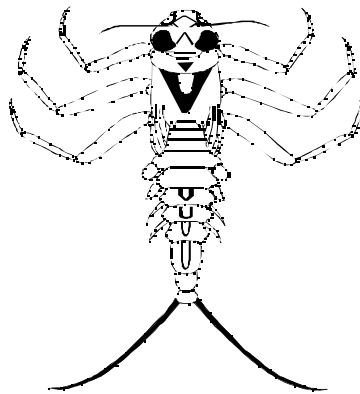


**Macroinvertebrate Monitoring as an Indicator of Water Quality:
Status Report for Wilson's Creek and Skeggs Branch,
Wilson's Creek National Battlefield, 1988-2001**

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INTRODUCTION

The National Park Service (NPS) began monitoring the aquatic macroinvertebrates of Wilson's Creek in 1988, with three years of baseline data collected for the period 1988-1990 (Harris et al. 1991). Sporadic sampling continued during the period 1992-1995, with funding provided by the Midwest Regional Office of NPS. Concerted monitoring efforts began again in 1996, following creation of the Prairie Cluster Prototype Long-term Ecological Monitoring (Prairie Cluster LTEM) Program – a base-funded science program to monitor natural resources at Wilson's Creek National Battlefield and five other Midwestern NPS units. The purpose of this report is to summarize macroinvertebrate monitoring data collected from 1996 through 2001, and to compare macroinvertebrate community structure to the 1988-1990 baseline.

The objectives of this biomonitoring program are to determine the annual status of stream macroinvertebrate communities in order to assess the overall biotic integrity of Wilson's Creek and to detect changes through time in macroinvertebrate communities. Benthic macroinvertebrates are the most common group of organisms used to assess water quality (Rosenberg and Resh 1993). They are useful as indicators because they represent a diverse group of relatively long-lived, sedentary species that react strongly and often predictably to human influences on aquatic systems (Cairns and Pratt 1993).

BACKGROUND

Wilson's Creek, a tributary of the James River, meanders from north to south for about 4.8 km through the center of Wilson's Creek National Battlefield (Harris et al. 1991). The creek enters the James River 1.6 km south of the battlefield, ultimately flowing into Table Rock Lake. The James River basin drains the Springfield Plateau region of the Ozark Highlands. Skeggs Branch, a tributary, joins Wilson's Creek near the center of the battlefield. The Wilson's Creek drainage basin lies in southwestern Missouri, in Greene and Christian Counties (Black 1997). Wilson's Creek originates in Springfield, the third largest city in Missouri (pop. 151,580); Skeggs Branch originates near the town of Republic (pop. 8,438).

The natural vegetation of the area is a mosaic of oak-hickory forest and woodland, tallgrass prairie and limestone glade communities, with forested river corridors (Gremaud 1986; Nelson 1987). The area is part of Omernick's (1987) Ozark Highlands ecoregion, which is topographically characterized by open and high hills.

Seventy-one percent of the Wilson's Creek drainage falls within Greene County, Missouri, the remaining in Christian County (Black 1997). Between 1990 and 2000 Greene county had the second largest growth in population within the state of Missouri, 32,442 individuals (15.5% increase; Missouri 2000 Census Figures). Christian County had the largest percent growth within the state of Missouri, 66.3 % increase (21,641 individuals). Accompanying changes in population growth were increases in new home and commercial construction starts. For example, Springfield issued an average of 444 permits per year for new home constructions between 1996 and 2000 (Springfield Business and Development Corporation 2001). New commercial construction permits increased from 85 in 1996 to 144 in 2000. Conversion of land use from rural to urban accompanied these new building starts.

POLLUTION HISTORY

Historic and recent monitoring show that several contaminants threaten Wilson's Creek. Recent improvements in wastewater treatment have eliminated major portions of Wilson's Creek contaminant burden. However, land conversion associated with urban development may now be the major source of contamination.

Black (1997) gives an extensive review of the pollution history of Wilson's Creek, which is summarized here. In the early 1800s Wilson's Creek was a clear, spring-fed stream. However, by the late 1800s water conditions had deteriorated precipitously due to raw sewage release from the developing city of Springfield. Springfield's first modern sewage treatment plant opened in 1910 releasing effluent into a tributary of Wilson's Creek. The sewage treatment plant was moved to its current location along Wilson's Creek in 1959 and upgraded significantly in 1962, 1978, and 1993. Phosphorous removal was added to the system in 1996 and upgraded in 2001. Current capacity of the treatment plant is 42.5 million gallons per day of treated sewage with effluent released directly into Wilson's Creek. Development within the Wilson's Creek watershed between treatment plant upgrades often out-paced the benefits from increased treatment plant capacity, resulting in cyclic re-occurrence of poor water quality preceding treatment plant improvements.

The State of Missouri declared approximately 29 km of Wilson's Creek as water-quality impaired (Missouri Department of Natural Resources 1998). Data from Nimmo et al. (1989) and others demonstrated toxicity in Wilson's Creek, which has been corroborated by reports of biological impoverishment (Missouri Department of Natural Resources 2002). The state attributes this toxicity to non-point source pollution from urban areas and considers Wilson's Creek a high priority for development of a total maximum daily load (TMDL), as required by the Clean Water Act.

Richards and Johnson (2002) investigated the toxicity of base flow and urban stormwater runoff into Wilson's Creek and found that fecal indicator bacteria densities exceeded the state limit for whole-body-contact recreation at all but one site during base flow conditions. During storm events, fecal indicator bacteria densities were orders of magnitude greater than the state limits. Based on organic compounds detected in stormwater samples and evidence of genotoxicity, Richards and Johnson (2002) also concluded that the water quality of the Wilson's Creek Basin was being degraded by urban derived contaminants. The predominant contaminants were polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs), probably derived from petroleum products or combustion sources. These contaminants are commonly washed off parking lots and roadways during storms.

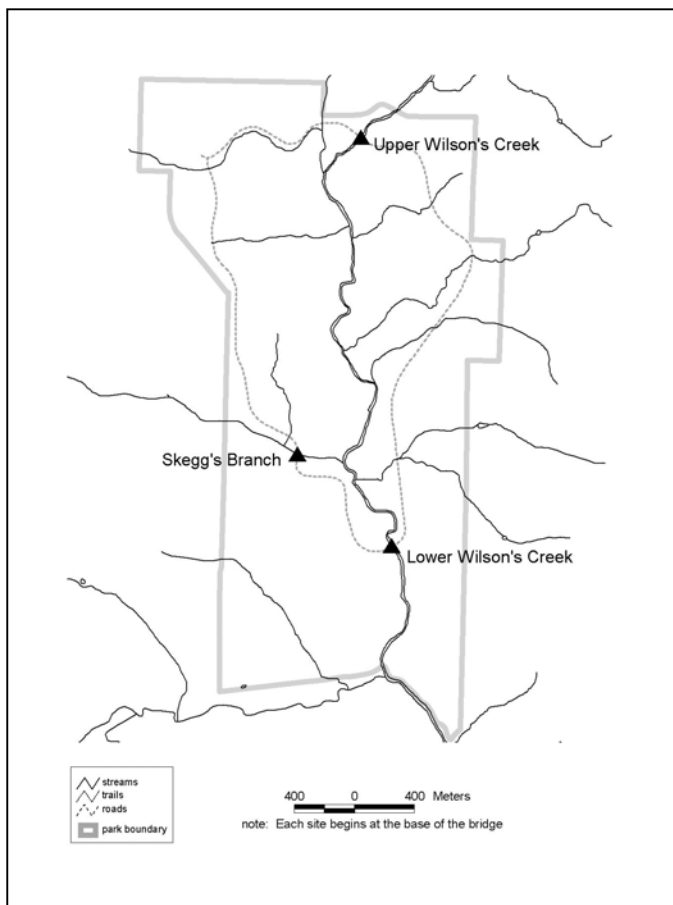
METHODS

FIELD AND LABORATORY PROCEDURES

The details of field and laboratory procedures are described in Peterson et al. (1999), and summarized below.

Monitoring Sites. Harris et al. (1991) established three monitoring sites within the park, two along Wilson's Creek and one on Skeggs Branch (Figure 1). Criteria for site selection probably included capturing stream quality at points of entry and exit from the park, coverage of major tributaries within the park and ease of access. Five replicate Surber samples were collected at each site during each sampling event.

Figure 1. Macroinvertebrate monitoring sites at Wilson's Creek National Battlefield, MO.



Sampling Frequency and Timing. Five replicate samples were collected from each of three sites at approximate monthly intervals during a summer sampling window defined by growing degree days (i.e. days with average daily temperature above 10°C). For Wilson's Creek National Battlefield, normal average daily temperatures fall within this range for the period 1 June through 10 August (National Weather Service). The samples included in this report were collected between 5 June and 3 September.

Field Sampling. Benthic macroinvertebrate samples were collected from shallow riffle areas of the stream with a Surber sampler following methods outlined by Peterson et al. (1999). Colorado State University investigators collected macroinvertebrate samples for the period, 1988-1990 (Harris et al. 1991). Park staff collected macroinvertebrate samples for the period 1996-2001. To minimize disturbance to a site prior to sampling, samples were collected from the most downstream riffle at a site first, and progressed upstream until five replicate samples

were collected. A small rake (trowel) was used to dislodge organisms from the substrate inside the sampler. Cobble inside the sampler was scrubbed with a vegetable brush to dislodge additional organisms. Macroinvertebrates were carefully removed from the sampler and placed in labeled jars containing 80 % ethyl alcohol. Samples were then prepared for shipping and sent to the laboratory for species identification and enumeration.

Laboratory Procedures. Macroinvertebrates were identified and enumerated by Dr. Boris Kondratieff's laboratory, Colorado State University for the period 1988-1990 (Harris et al. 1991); and by Dr. Charles Rabeni's laboratory, Missouri Cooperative Fish and Wildlife Research Unit, University of Missouri-Columbia for 1996-2001. Macroinvertebrates were identified to the lowest taxonomic level possible, which was generally to genus.

COMMUNITY INDICES

The monitoring protocol recommended using a suite of four community indices to describe changes in community structure (Table 1) (Peterson et al. 1999). Peterson (1996) used Pearson correlation comparisons and a Principal Components Analysis of the correlation matrix to select four indices from a possible list of nine metrics. We have included Taxa Richness and EPT Richness in this summary for purposes of comparison with macroinvertebrate monitoring data from other sources.

Table 1. Metrics used to characterize the aquatic macroinvertebrate community of Wilson's Creek and Skeggs Branch, Wilson's Creek National Battlefield, MO and chosen as indicative of changing water quality through time. An asterisk indicates metrics originally selected by Peterson (1996).

Metric(Reference)	Definition	Expected Response
Taxa Richness (Resh and Grodhaus 1983)	Number of taxa present per sample.	Lower richness indicates declining water quality.
Family Richness* (Resh and Grodhaus 1983)	Number of families present per sample.	Lower richness indicates declining water quality.
Family Diversity* (Shannon-Wiener 1949)	$H' = -\sum(n_i / N) * \ln(n_i / N)$ N is the total number of individuals in a sample; n_i is the total number of individuals in the i th family.	Includes a measure of richness and evenness. Lower diversity indicates declining water quality.
Family Biotic Index* (Hilsenhoff 1988)	$FBI = \sum n_i a_i / N$ N is the total number of individuals in a sample, n_i is the total number of individuals in a family, and a_i the tolerance value for the i th family.	This index weights the relative abundance of each family by its relative pollution tolerance value to determine a community score. Pollution-tolerant species are weighted more heavily than pollution-sensitive species in the index. Higher FBI indicates declining water quality.
EPT Richness (Resh and Grodhaus 1983)	Number of Ephemeroptera, Plecoptera, and Trichoptera taxa present per sample.	The majority of taxa in these three orders are pollution sensitive. Lower EPT richness indicates declining water quality.
EPT Ratio* (Resh and Grodhaus 1983)	$EPT / (EPT + Chironomidae)$ The number of EPT individuals in a sample divided by this sum plus the number of Chironomidae.	The EPT ratio varies between 0 and 1. Ratio values close to 0 describe low EPT densities relative to Chironomidae and EPT densities, and indicate declining water quality.

DATA ANALYSIS

The macroinvertebrate indices for Wilson's Creek were compared using analysis of variance (ANOVA). There were too few data points from Skeggs Branch to attempt a similar analysis. An initial examination of the Wilson's Creek data suggested that there were too few data points within some years to appropriately make between-year comparisons. Specifically, in 1988, 1990 and 2000, samples were collected on only one date. This was of particular concern because we observed that June samples tended to be somewhat less diverse and more variable than July or August samples. The division of the data into four time periods was based on two factors. First, park management wanted to determine how the macroinvertebrate community had changed following expansion of Springfield's Southwest Sewage Treatment Plant in 1993. If water quality had improved following the expansion, was that improvement sustained over a period of years? Secondly, we wanted to break the data into reasonably comparable groups that included a balance of sampling dates and a similar number of samples. The time periods 1 through 4

include 4, 5, 5, and 4 sampling dates, respectively. On each date, two sites were sampled with five observations (replicates) at each site.

Between period variation in community indices across sites was assessed with a mixed model ANOVA (SAS procedure MIXED: Littell et al. 1996). Site was treated as a fixed factor and date within year as a random factor. This was consistent with Peterson's (1996) mixed model treatment of the 1989 data. Period, and year within period were treated as fixed factors. The full model is described below.

$$Y_{ijklm} = \mu + \alpha_i + \beta_j + \alpha_i\beta_j + \gamma_{k(i)} + \varepsilon_{l(ki)} + \eta_{m(jlki)}$$

α_i = Period effect (fixed factor)

β_j = Site effect (fixed factor)

$\alpha_i\beta_j$ = Interaction term between period and site

$\gamma_{k(i)}$ = Year effect nested within period (fixed factor)

$\varepsilon_{l(ki)}$ = Error associated with the particular sampling date (random factor).
This error term is nested within year since those dates and their associated weather and stream conditions were unique for that year. Both sites were sampled on all dates.

$\eta_{m(jlki)}$ = Error associated with the m th observation on the j th site for the l th date of the k th year of the i th period (5 observations per site on each date).

PHYSICAL AND CHEMICAL WATER QUALITY DATA

Springfield's Southwest Wastewater Treatment Plant (WWTP) personnel monitor effluent discharge and chemistry pursuant to their NPDES permit. Since 1993, the WWTP has also collected monthly data in Wilson's Creek at the WICR upstream boundary. These data include, but are not limited to, stream discharge, total phosphorus, and total nitrogen. Plant laboratory personnel provided all data collected by the plant over the last 10+ years. Monthly total phosphorous data from Wilson's Creek were analyzed graphically as annual means. On dates that streamflow data were collected in Wilson's Creek, mean daily discharge from the treatment plant was obtained from the data record. The contribution of wastewater effluent to Wilson's Creek flow was considered an important indicator of water quality because the potential diluting effect of the stream receiving water would be apparent. Springfield WWTP monitoring data was also scanned, but there was little evidence of effluent exceedences. Because the data were collected monthly, there was limited ability to draw inferences about potential episodic events. Consequently, these data were not used further in the analysis.

RESULTS AND DISCUSSION

BIOLOGICAL DATA

The macroinvertebrate indices across the four time periods are reported in Tables 2 and 3, for Wilson's Creek and Skeggs Branch, respectively. The data are also reported by date and sampling site in Appendix A.

Wilson's Creek: The Wilson's Creek results are presented graphically in Figure 2. The results of the mixed model ANOVA for the Wilson's Creek data are presented in Table 4.

Taxa Richness varied significantly across time periods, declining through time from Period 2 through Period 4 (Table 4, Figure 2a). While Taxa Richness was significantly lower in Period 1 compared to Period 2, this result should be interpreted cautiously due to differences in the level of taxa identification conducted by one laboratory for Period 1 and by another for Periods 2, 3 and 4. Family Richness displayed a similar, but more variable pattern (Table 4, Figure 2b). Family Richness was significantly lower in Period 4 in comparison to Periods 1, 2 and 3. Family Diversity also varied significantly across time periods, with higher diversity reported in Period 3 in comparison to the other periods (Table 4, Figure 2c).

EPT Taxa Richness increased from Period 1 to Period 2, followed by a slight declining trend across Periods 2, 3 and 4 (Table 4, Figure 2d). The EPT Ratio varied significantly across time periods with the highest values observed in Period 3 (Table 4, Figure 2e). The Family Biotic Index did not vary significantly across time periods, although the highest mean values (i.e. poorest water quality) occurred in Period 4 (Table 4, Figure 2f).

Table 2. Wilson's Creek, Wilson's Creek National Battlefield, MO macroinvertebrate indices; least square means and standard errors.

Macroinvertebrate Index	Period 1 (1988-1990)	Period 2 (1996-1997)	Period 3 (1998-1999)	Period 4 (2000-2001)
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)
Taxa Richness	14.0 (1.003)	19.9 (0.869)	16.5 (0.869)	12.5 (1.100)
Family Richness	10.7 (0.786)	11.5 (0.681)	10.4 (0.681)	7.2 (0.861)
Family Diversity	1.09 (0.054)	1.19 (0.047)	1.44 (0.047)	1.14 (0.060)
EPT Richness	2.8 (0.559)	4.9 (0.484)	4.4 (0.484)	3.6 (0.613)
EPT Ratio	0.29 (0.061)	0.26 (0.052)	0.47 (0.052)	0.25 (0.066)
Family Biotic Index	5.85 (0.142)	5.89 (0.123)	5.83 (0.123)	6.19 (0.155)

Skeggs Branch: There was insufficient data from Skeggs Branch to warrant statistical analysis. The data are graphically displayed in Figure 3.

Skeggs Branch exhibited a decline in Taxa Richness (Figure 3a), Family Richness (Figure 3b) and Family Diversity (Figure 3c) from Period 2 to Periods 3 and 4. EPT Richness (Figure 3d) was lowest in Period 3 compared to the other time periods. The EPT Ratio (Figure 3e) was highest in Period 1, showed a marked decline in Periods 2 and 3, and improved somewhat in Period 4. The Family Biotic Index (Figure 3f) showed little variation across the four time periods.

Table 3. Skeggs Branch, Wilson's Creek National Battlefield, MO macroinvertebrate indices; least square means and standard errors.

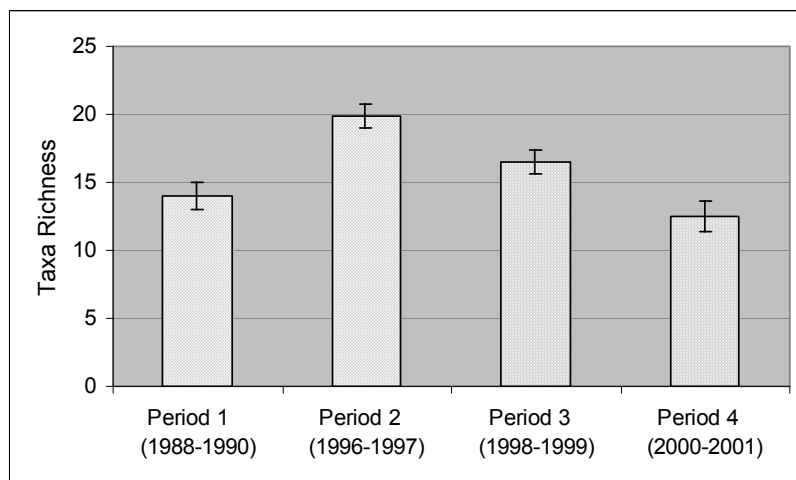
Macroinvertebrate Index	Period 1 (1988-1990)	Period 2 (1996-1997)	Period 3 (1998-1999)	Period 4 (2000-2001)
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)
Taxa Richness	20.4 (1.024)	25.8 (1.374)	20.0 (1.374)	18.7 (1.122)
Family Richness	15.4 (0.593)	17.3 (0.796)	12.5 (0.796)	10.9 (.650)
Family Diversity	1.90 (0.054)	1.96 (0.073)	1.70 (0.073)	1.76 (0.060)
EPT Richness	5.2 (0.351)	5.1 (0.471)	2.8 (0.471)	4.9 (0.384)
EPT Ratio	0.62 (0.043)	0.27 (0.058)	0.29 (0.058)	0.45 (0.047)
Family Biotic Index	5.73 (0.099)	6.12 (0.133)	5.50 (0.133)	5.21 (0.108)

Table 4. Mixed Model ANOVA Results for Wilson's Creek, Wilson's Creek National Battlefield, MO.

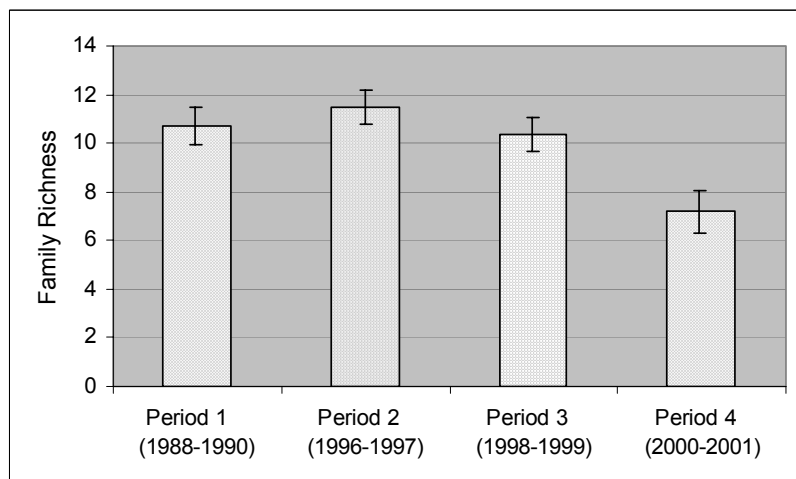
Taxa Richness	Effect	Num DF	Den DF	F-Ratio	p-value
	Period	3	18	11.40	0.0002
	Site	1	162	0.14	0.7122
	Site * Period	3	162	0.38	0.7662
	Year (Period)	5	18	2.94	0.0413
Pairwise comparisons: Period 1 vs. 2, p-value = 0.0003 Period 2 vs. 3, p-value = 0.0137 Period 2 vs 4, p-value < 0.0001 Period 3 vs 4, p-value = 0.0100					
Family Richness	Effect	Num DF	Den DF	F-Ratio	p-value
	Period	3	18	5.43	0.0078
	Site	1	162	0.17	0.6768
	Site * Period	3	162	0.68	0.5664
	Year (Period)	5	18	2.27	0.0918
Pairwise comparisons: Period 1 vs. 4, p-value = 0.0074 Period 2 vs. 4, p-value = 0.0010 Period 3 vs. 4, p-value = 0.0096					
Family Diversity	Effect	Num DF	Den DF	F-Ratio	p-value
	Period	3	18	9.86	0.0005
	Site	1	162	1.37	0.2433
	Site * Period	3	162	4.69	0.0036
	Year (Period)	5	18	13.45	<0.0001
Pairwise comparisons: Period 1 vs. 3, p-value = 0.0001 Period 2 vs. 3, p-value = 0.0014 Period 4 vs. 3, p-value = 0.0009					
Family Biotic Index	Effect	Num DF	Den DF	F-Ratio	p-value
	Period	3	18	1.25	0.3220
	Site	1	162	16.78	<0.0001
	Site * Period	3	162	5.61	0.0011
	Year (Period)	5	18	5.61	.0027
EPT Taxa Richness	Effect	Num DF	Den DF	F-Ratio	p-value
	Period	3	18	2.96	0.0599
	Site	1	162	4.92	0.0280
	Site * Period	3	162	0.26	0.8549
	Year (Period)	5	18	2.64	0.0586
Pairwise comparisons: Period 1 vs. 2, p-value = 0.0123 Period 1 vs. 3, p-value = 0.0473					
EPT Ratio	Effect	Num DF	Den DF	F-Ratio	p-value
	Period	3	18	3.38	0.0411
	Site	1	162	0.06	0.8038
	Site * Period	3	162	0.81	0.4882
	Year (Period)	5	18	4.32	0.0093
Pairwise comparisons: Period 1 vs. 3, p-value = 0.042 Period 2 vs. 3, p-value = 0.014 Period 4 vs. 3, p-value = 0.021					

Figure 2. Wilson's Creek, Wilson's Creek National Battlefield, MO macroinvertebrate index means (and standard errors) among periods.

a. Taxa Richness



b. Family Richness



c. Family Diversity

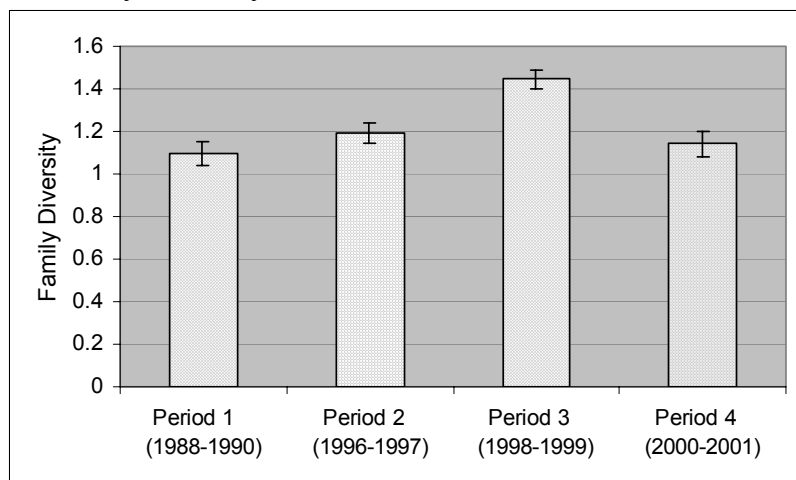
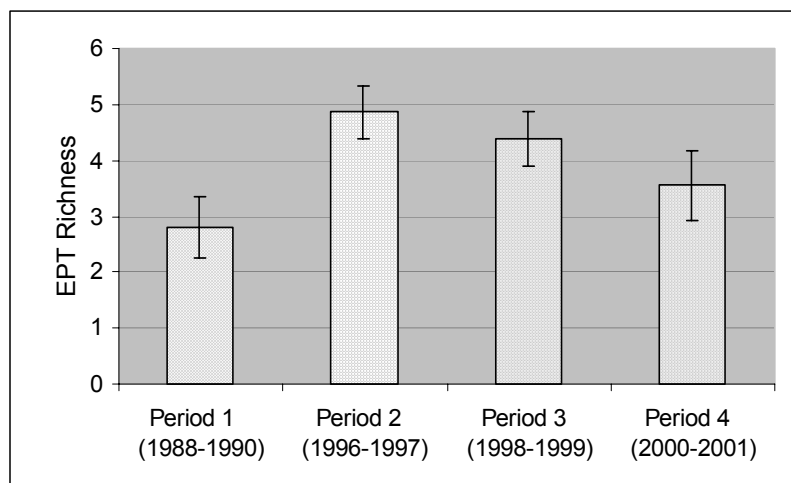
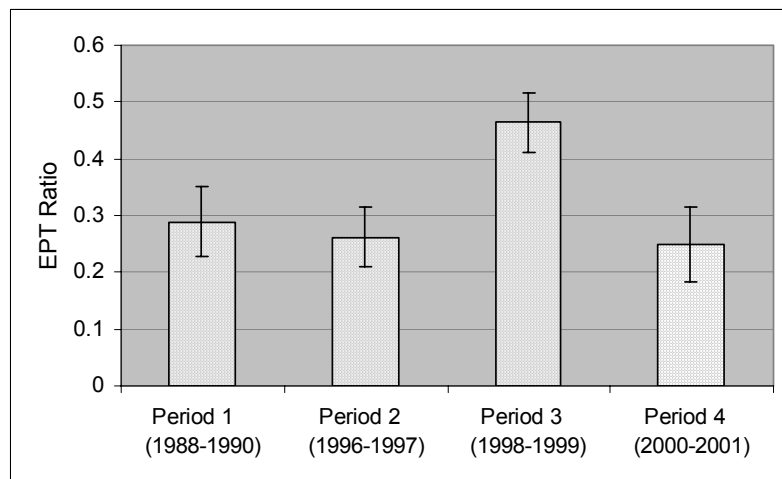


Figure 2 cont'd. Wilson's Creek, Wilson's Creek National Battlefield, MO macroinvertebrate index means (and standard errors) among periods.

d. EPT Richness



e. EPT Ratio



f. Family Biotic Index

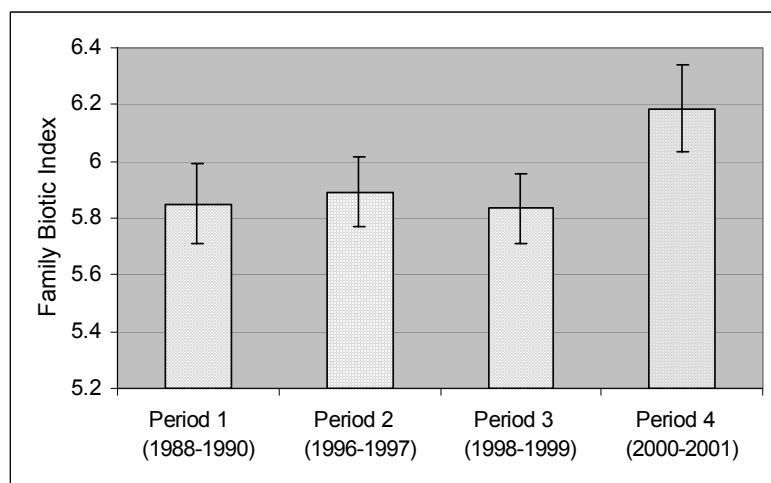
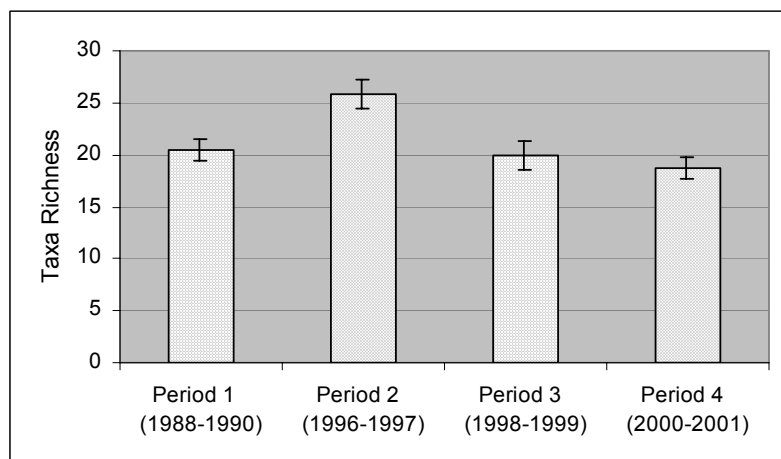
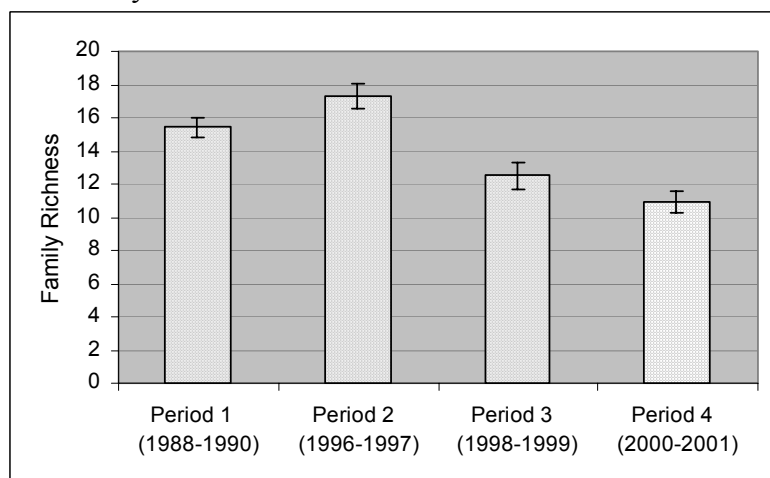


Figure 3. Skeggs Branch, Wilson's Creek National Battlefield, MO macroinvertebrate index means (and standard errors) among periods.

a. Taxa Richness



b. Family Richness



c. Family Diversity

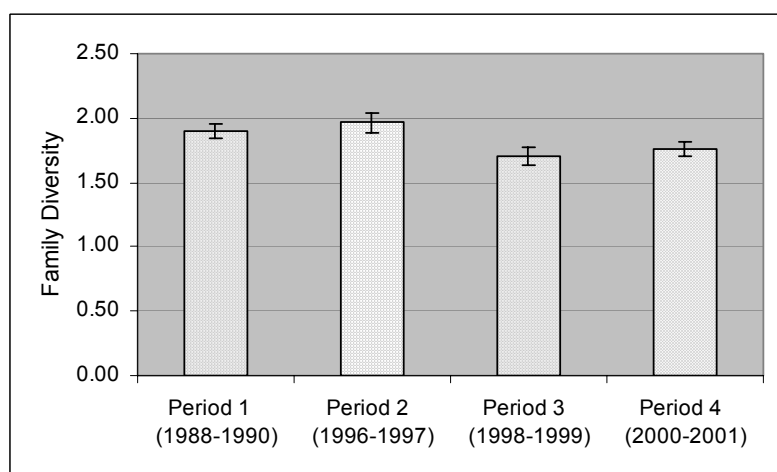
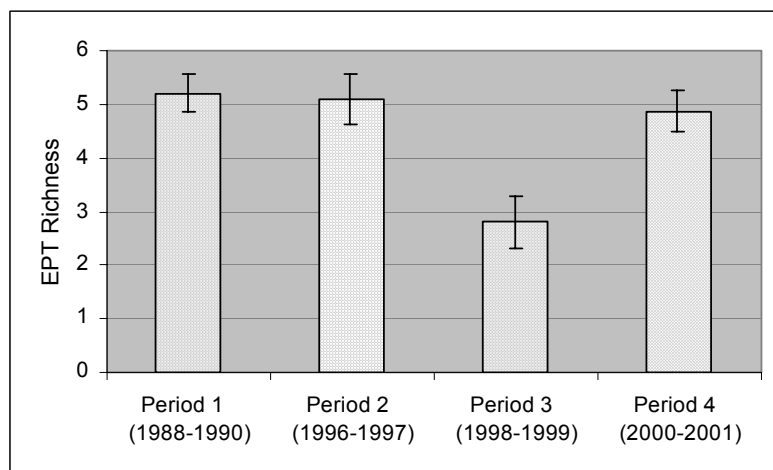
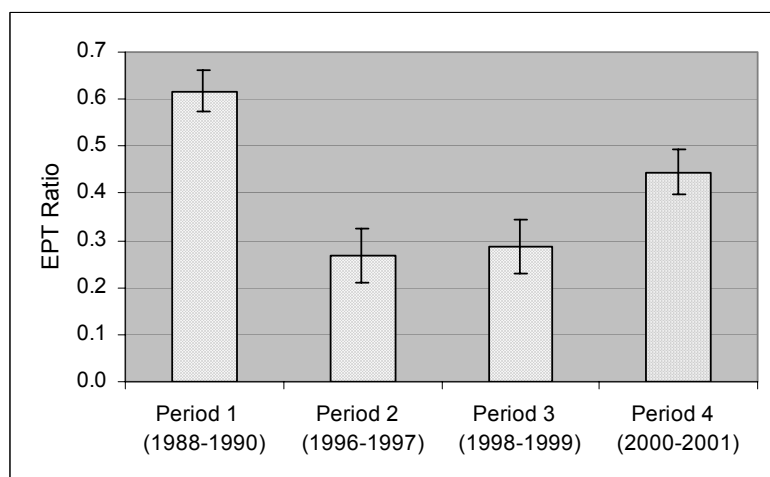


Figure 3 cont'd. Skeggs Branch, Wilson's Creek National Battlefield, MO macroinvertebrate index means (and standard errors) among periods.

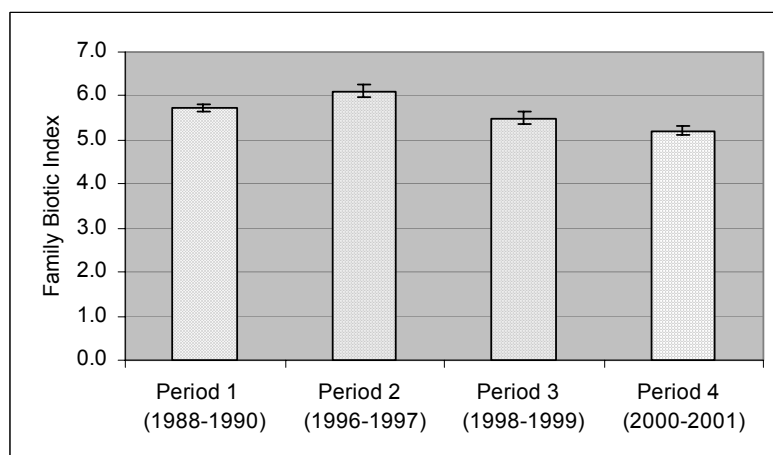
d. EPT Richness



e. EPT Ratio



f. Family Biotic Index



Wilson's Creek exhibited a decline in Taxa Richness from Period 2 through Period 4. The same pattern is apparent to a lesser degree for Family Richness. EPT Richness increased from Period 1 to Period 2, followed by a slight decline in the latter periods. A closer examination of the data revealed that a number of taxa were collected less frequently in the latter time periods (Table 5). Some of these taxa, including *Leptoceridae* and *Corydalus*, are sensitive to contaminants.

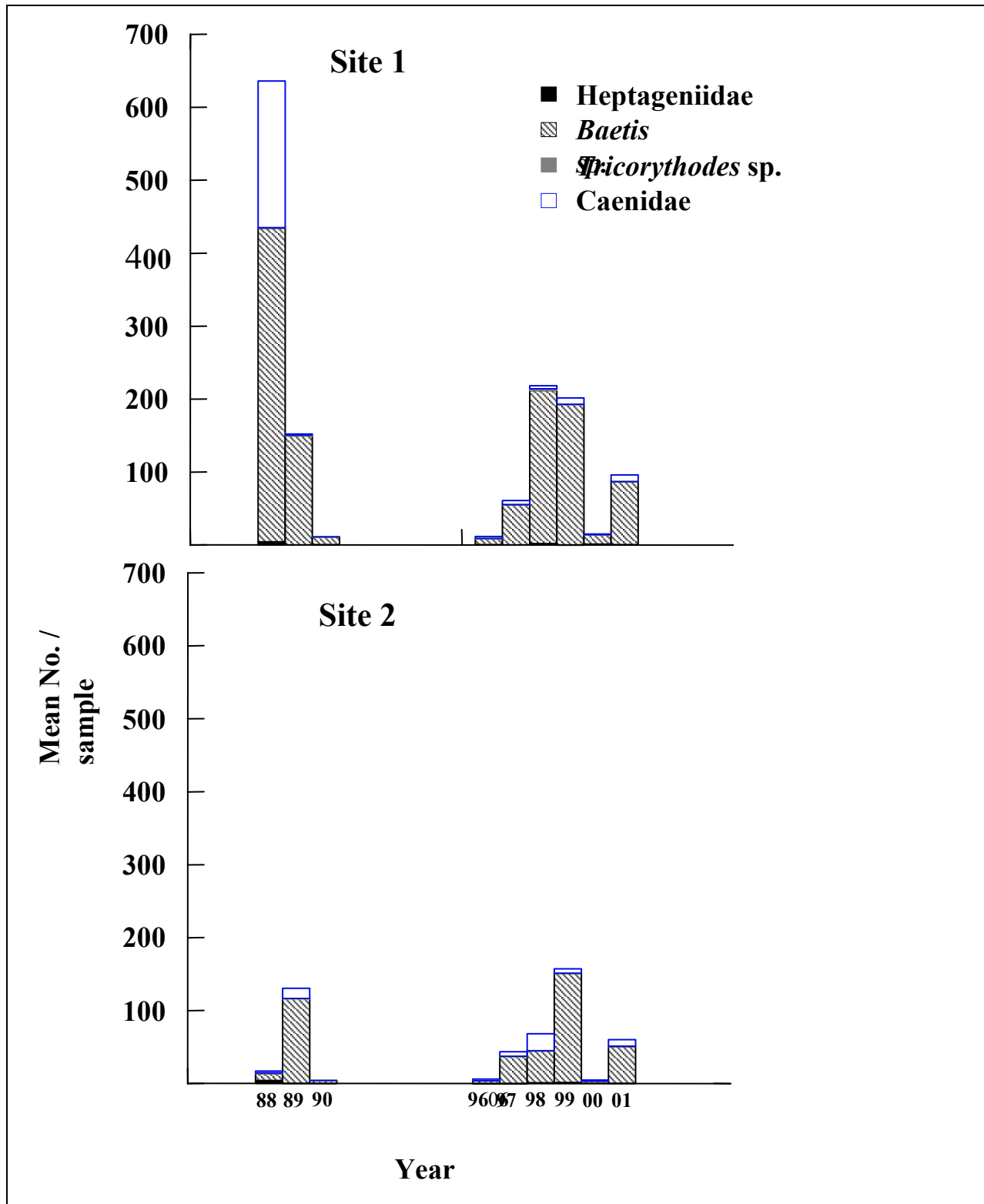
Table 5. Macroinvertebrate taxa less commonly collected in Wilson's Creek, Wilson's Creek National Battlefield, MO during Periods 3 and 4.

Order	Family	Genus	Common Name
Hydrocarina	Hydrachnidae	<i>Hydrachna</i>	water mites
	Sperchonidae	<i>Sperchon</i>	water mites
Trichoptera	Leptoceridae	<i>Nectopsyche</i> , <i>Paraleptophlebia</i> , <i>Trionodes</i>	caddisflies
Megaloptera	Corydalidae	<i>Corydalus</i>	hellgrammites
Coleoptera	Hydrophilidae	<i>Berosus</i>	hydrophillid beetles
Diptera	Chironomidae	<i>Parapheocladus</i> , <i>Phaenopsectra</i> , <i>Rheocricotopus</i>	midges
Diptera	Simuliidae	<i>Simulium</i>	black flies

Family Diversity and the EPT Ratio were highest in Period 3. Both may be explained by higher EPT densities in relation to chironomid densities. Family Diversity is a function of family richness and the evenness of abundance among represented families. Period 3 saw a decline in chironomid density and higher EPT densities. These indices suggest an improvement in water quality during Period 3.

A more detailed examination of EPT taxa and their occurrence reveal two additional patterns. First, over the course of the study, stoneflies (Plecoptera) were never captured in Wilson's Creek, while five taxa were frequently found in Skeggs Branch. Stoneflies are among the most sensitive stream insects to low dissolved oxygen levels and other contaminants (Stewart and Stark 1993). Although the absence of a taxon in samples does not prove its absence from a stream, the fact that stoneflies were consistently captured in Skeggs Branch but never in Wilson's Creek carries implications. Despite the presence of adequate gravel and cobble substrate, the consistent absence of stoneflies in Wilson's Creek suggests poor water quality. Second, mayfly (Ephemeroptera) abundance in Wilson's Creek was sporadic over the 9-year period. Four taxa were consistently collected, with *Baetis* clearly dominant (Figure 4). *Baetis* are considerably more tolerant of contaminants than most mayflies (Barbour et al. 1999). Heptageniidae are considered the most sensitive mayfly taxon to most human disturbance (Barbour et al. 1999) and were present in Wilson's Creek sporadically and in low numbers. Dominance by the pollution-tolerant *Baetis* among mayflies supports the conclusion that Wilson's Creek water quality is generally poor. However, mean annual abundance of mayflies varied dramatically in Wilson's Creek since 1988, and should be interpreted cautiously. A notable drop in mayfly abundance was apparent in 2000, which may have been associated with several large floods that occurred that year. Because *Baetis* are swimmers and therefore prone to water current, large flow events can substantially reduce their populations. A significant raw sewage spill also occurred in 2000 and cannot be ruled out as a possible causative factor.

Figure 4. Mean number of individuals per sample at 2 sites on Wilson's Creek, Wilson's Creek National Battlefield, MO 1988-2001.



PHYSICAL AND CHEMICAL WATER QUALITY DATA

Wilson's Creek mean annual concentration of total phosphorous (collected at north park boundary, Wilson's Creek National Battlefield) is reported in Figure 5. Total phosphorous concentrations declined in 1996 and again in 2001. Consistent annual declines of total phosphorous in Wilson's Creek were associated with known reductions in WWTP effluent, and therefore provide evidence that nutrient (phosphorous) inputs to the ecosystem have been reduced. Annual variation in dissolved total phosphorous concentrations in Wilson's Creek corresponded to changes in WWTP operations. The decline in phosphorous concentrations after 1996 corresponds to the beginning of biological removal of phosphorous in the treatment plant. The maximum phosphorous removal through biological treatment was apparently reached soon afterwards, and is probably responsible for the observed plateau in phosphorus concentrations from 1998-2000. A further upgrade at the WWTP allowed chemical removal of phosphorous and became functional in 2001. This upgrade probably caused the observed additional decline in total phosphorous concentrations in 2001.

The contribution of WWTP effluent to Wilson's Creek discharge is reported in Figure 6. There was a marked decline in the proportion attributable to effluent in 1998. Annual reductions in the contribution of WWTP effluent to Wilson's Creek discharge may be indicative of improving water quality. Although the data are neither continuous nor available prior to 1994, they suggest that there is less concentrated effluent in Wilson's Creek currently relative to pre-1997 levels. The cause for this trend may also be related to WWTP management activities. Although somewhat counter-intuitive, aged and porous sewer lines in the Springfield area are usually infiltrated by groundwater rather than leak into the surrounding soil. Consequently, groundwater that would have otherwise contributed to natural stream discharge is "diverted" into the wastewater system. Aged pipes in the Springfield WWTP system have been actively replaced in the last 4 years, which has presumably halted much of the groundwater diversion into sewer lines. As a result, both the total effluent discharge and the proportion of stream flow composed of effluent have declined. However, the potential diluting effect afforded by higher levels of groundwater in the stream would be trivial if, as a consequence of less groundwater infiltration in the WWTP system, the WWTP effluent was more concentrated. Although concentrations of constituents for which the WWPT is permitted have not increased, other untreated chemicals may have become more concentrated in recent years.

SUMMARY AND CONCLUSIONS

Macroinvertebrate communities provide an integrated yet complex characterization of Wilson's Creek water quality. An increase in EPT Richness from Period 1 (1988-1990) to Period 2 (1996-1997) suggests an improvement in water quality following the expansion of Springfield's Southwest Wastewater Treatment Plant in 1993 and addition of phosphorous removal in 1996. However, the subsequent decline in Taxa and Family Richness indicate that water quality then declined. In contrast, Family Diversity and the EPT Ratio suggest an improvement in water quality during Period 3 (1998-1999). Such an improvement would be consistent with the observed decline in the proportion of Wilson's Creek discharge attributed to WWTP effluent.

Despite some contradictory results of community indices, the consistent absence of pollution-sensitive species and high abundances of pollution-tolerant species indicate that water quality in Wilson's Creek remains degraded. In the context of comparable Missouri streams, biological communities in Wilson's Creek are impoverished. Consequently, apparent short-term improvements in water quality observed in this study represent little evidence that conditions have changed over the last 10 years.

Figure 5. Mean annual concentration of total phosphorous in Wilson's Creek at north park boundary, Wilson's Creek National Battlefield, MO. Error bars represent plus/minus 1 standard error from 12 monthly samples. *Data courtesy Springfield Southwest Wastewater Treatment Plant.*

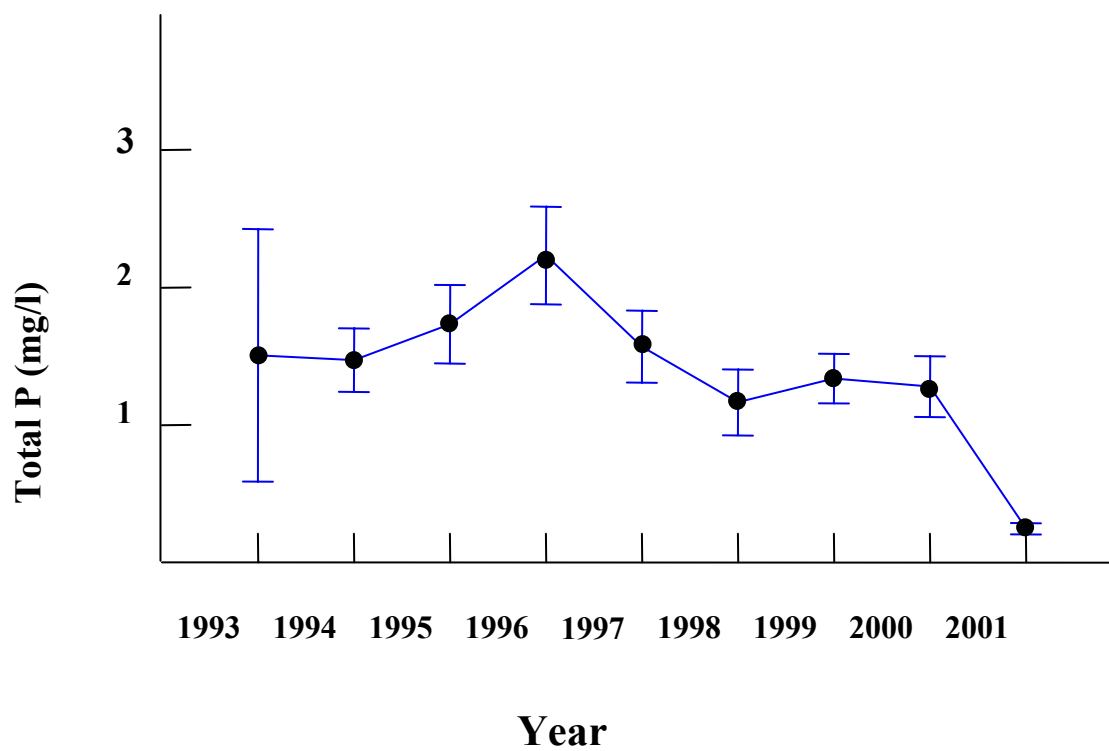
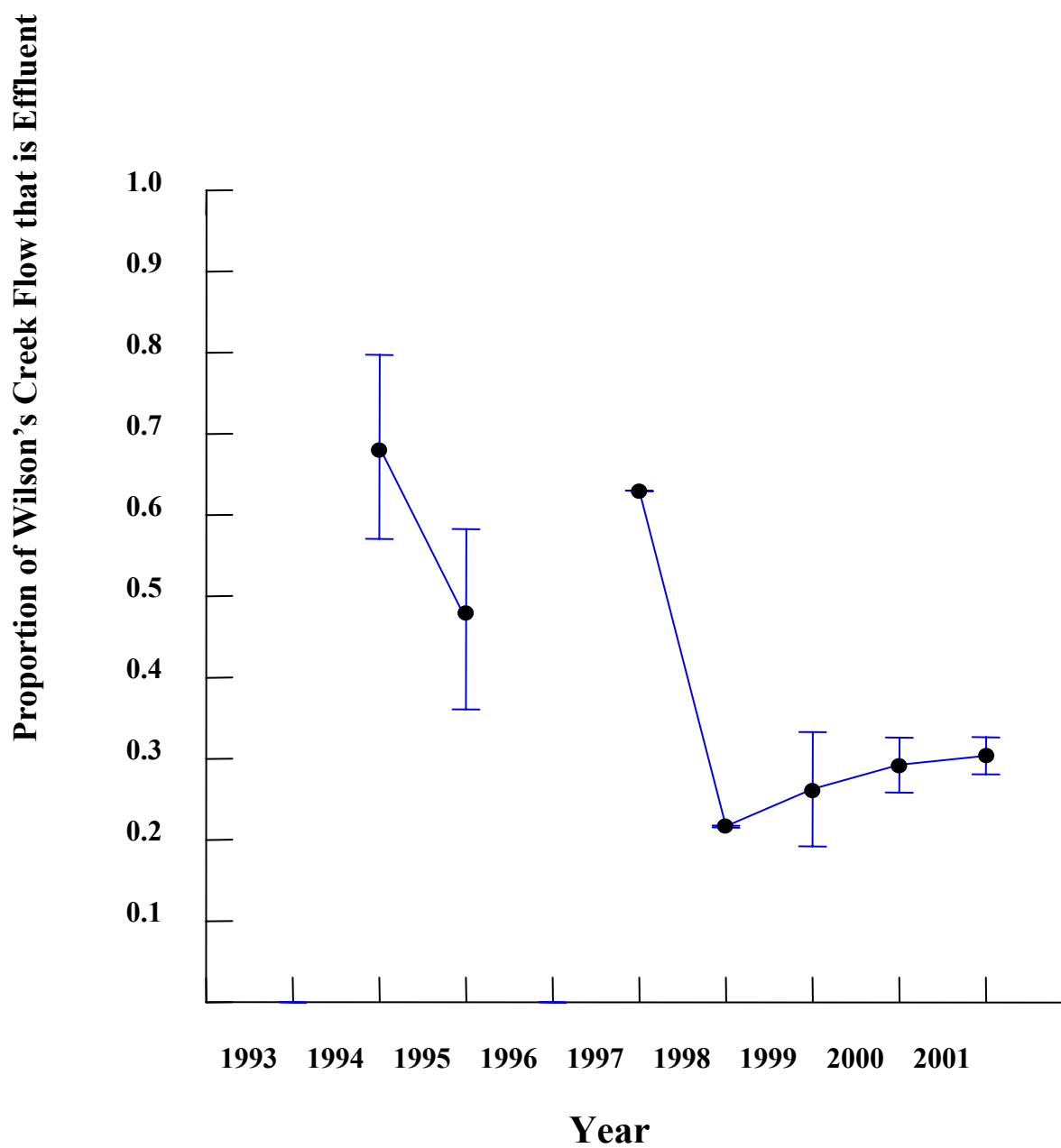


Figure 6. Mean annual proportion of Wilson's Creek flow that is composed of WWTP effluent. Error bars represent plus/minus 1 standard error of 4-6 samples. *Data courtesy Springfield Southwest Waste Water Treatment Plant.*



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Appendix A. Means (SE) of macroinvertebrate indices for Wilson's Creek and Skeggs Branch, Wilson's Creek National Battlefield, MO by date and sample site.

Date	N	Family Diversity	Family Richness	FBI	EPT Ratio	EPT Richness	Taxa Richness
Wilson's Creek Upper							
8/15/88	5	1.31 (0.19)	11.0 (1.52)	5.46 (0.24)	0.70 (0.09)	4.2 (0.49)	13.4 (1.60)
6/26/89	5	1.05 (0.10)	13.0 (0.63)	5.68 (0.06)	0.20 (0.03)	2.0 (0.00)	16.0 (0.63)
8/15/89	5	0.86 (0.06)	12.2 (0.58)	5.71 (0.10)	0.21 (0.02)	3.6 (0.24)	16.4 (0.81)
6/27/90	5	0.71 (0.08)	9.8 (1.16)	6.72 (0.16)	> 0.01 (>0.001)	1.4 (0.24)	13.8 (1.16)
6/25/96	5	0.96 (0.11)	9.2 (0.80)	5.35 (0.17)	0.17 (0.02)	4.2 (0.37)	19.0 (1.58)
8/23/96	5	1.32 (0.07)	12.8 (0.92)	5.83 (0.14)	0.36 (0.06)	5.8 (0.58)	22.2 (1.28)
6/05/97	5	1.20 (0.18)	9.4 (1.44)	5.82 (0.12)	0.06 (0.03)	2.4 (0.93)	17.2 (2.89)
7/16/97	5	1.13 (0.09)	11.6 (1.12)	6.34 (0.18)	0.15 (0.06)	4.4 (0.75)	18.2 (2.63)
9/03/97	5	1.49 (0.18)	16.2 (1.02)	5.19 (0.21)	0.52 (0.10)	6.0 (0.32)	24.0 (1.22)
7/08/98	5	1.77 (0.07)	14.4 (2.01)	5.50 (0.20)	0.57 (0.06)	6.8 (0.66)	22.6 (2.58)
8/28/98	5	1.42 (0.04)	10.8 (0.73)	5.45 (0.29)	0.52 (0.11)	5.2 (0.49)	17.0 (0.95)
6/08/99	5	0.96 (0.10)	7.2 (0.49)	7.01 (0.13)	0.10 (0.04)	1.2 (0.37)	11.4 (1.44)
7/09/99	5	1.20 (0.16)	8.0 (1.61)	6.82 (0.17)	0.37 (0.13)	2.0 (0.84)	12.6 (3.14)
8/17/99	5	1.44 (0.05)	10.2 (0.58)	5.88 (0.28)	0.55 (0.12)	4.6 (0.40)	16.6 (1.91)
8/23/00	5	0.89 (0.10)	5.6 (0.40)	6.69 (0.18)	0.14 (0.05)	2.4 (0.68)	10.0 (0.77)
6/28/01	5	1.55 (0.10)	8.4 (0.51)	6.12 (0.13)	0.36 (0.06)	4.6 (0.40)	13.8 (0.73)
7/18/01	5	1.39 (0.05)	6.4 (0.81)	5.87 (0.28)	0.41 (0.08)	3.8 (0.37)	12.4 (1.12)
8/21/01	5	1.62 (0.07)	9.8 (0.86)	5.42 (0.12)	0.46 (0.07)	4.4 (0.51)	16.8 (1.98)
Wilson's Creek Lower							
8/15/88	5	1.62 (0.13)	9.0 (1.18)	5.20 (0.16)	0.52 (0.11)	3.6 (0.40)	10.6 (1.17)
6/26/89	5	1.18 (0.08)	11.2 (0.58)	5.27 (0.10)	0.32 (0.05)	2.0 (0.00)	14.6 (0.60)
8/15/89	5	1.29 (0.04)	13.6 (0.81)	5.70 (0.4)	0.30 (0.02)	4.8 (0.37)	18.6 (0.81)
6/27/90	5	0.73 (0.03)	9.4 (0.81)	6.50 (0.02)	> 0.01 (>0.001)	1.4 (0.24)	13.4 (0.81)
6/27/96	5	1.25 (0.09)	8.6 (0.75)	5.15 (0.19)	0.38 (0.05)	4.6 (0.40)	18.2 (2.22)
8/23/96	5	1.08 (0.06)	12.6 (0.68)	6.19 (0.09)	0.18 (0.03)	6.0 (0.63)	24.4 (1.75)
6/05/97	5	0.92 (0.07)	7.6 (0.93)	5.85 (0.06)	0.05 (0.02)	1.8 (0.58)	12.4 (1.66)
7/15/97	5	1.23 (0.04)	16.4 (0.87)	6.33 (0.15)	0.23 (0.02)	6.6 (0.40)	23.6 (1.63)
9/03/97	5	1.39 (0.08)	11.8 (1.46)	5.32 (0.14)	0.46 (0.08)	6.2 (0.66)	17.2 (2.27)
7/08/98	5	1.73 (0.06)	12.2 (0.66)	5.30 (0.07)	0.59 (0.03)	5.8 (0.20)	18.6 (1.33)
8/28/98	5	1.54 (0.06)	9.8 (0.92)	5.47 (0.22)	0.57 (0.10)	4.8 (0.66)	15.8 (2.60)
6/08/99	5	1.15 (0.14)	7.8 (0.37)	5.96 (0.24)	0.06 (0.02)	1.6 (0.51)	14.2 (1.02)
7/09/99	5	1.43 (0.10)	8.6 (0.68)	5.84 (0.29)	0.51 (0.07)	3.8 (0.20)	13.4 (1.47)
8/17/99	5	1.43 (0.08)	11.8 (0.66)	5.01 (0.20)	0.63 (0.09)	5.4 (0.24)	18.8 (0.86)
8/23/00	5	0.77 (0.10)	6.0 (0.55)	6.53 (0.12)	0.09 (0.02)	2.6 (0.24)	10.6 (0.68)
6/28/01	5	1.46 (0.04)	8.8 (0.66)	5.49 (0.11)	0.42 (0.07)	4.6 (0.75)	14.6 (0.81)
7/18/01	5	1.55 (0.09)	9.2 (0.86)	5.73 (0.20)	0.39 (0.06)	5.2 (0.37)	14.6 (1.44)
8/20/01	5	1.16 (0.17)	8.8 (1.36)	5.98 (0.26)	0.28 (0.08)	5.0 (0.55)	15.6 (2.25)
Skeggs Branch							
8/15/88	5	1.92 (0.12)	12.0 (1.52)	5.78 (0.26)	0.72 (0.09)	3.8 (0.37)	14.0 (2.05)
6/26/89	5	1.90 (0.06)	17.0 (0.84)	5.55 (0.21)	0.71 (0.06)	5.8 (0.37)	23.0 (0.71)
8/15/89	5	1.94 (0.06)	17.6 (1.21)	5.79 (0.33)	0.39 (0.06)	6.6 (0.51)	24.0 (1.38)
6/27/90	5	1.86 (0.02)	17.0 (1.05)	5.70 (0.08)	0.58 (0.04)	5.6 (0.75)	23.8 (1.28)
6/05/97	5	1.95 (0.07)	16.2 (1.69)	5.79 (0.11)	0.24 (0.05)	5.6 (1.63)	26.4 (4.37)
7/09/97	5	1.98 (0.06)	18.4 (1.12)	6.23 (0.22)	0.30 (0.05)	4.6 (0.81)	25.2 (2.31)
6/08/99	5	1.79 (0.07)	11.8 (1.77)	5.15 (0.15)	0.38 (0.09)	2.4 (0.51)	18.2 (2.75)
7/09/99	5	1.61 (0.20)	13.2 (0.80)	5.36 (0.35)	0.19 (0.09)	3.2 (0.58)	21.8 (1.56)
6/29/01	5	1.83 (0.14)	11.8 (0.48)	5.31 (0.09)	0.42 (0.09)	4.6 (0.40)	18.2 (1.39)
7/19/01	5	1.92 (0.06)	11.4 (0.60)	5.29 (0.16)	0.43 (0.05)	4.8 (0.66)	18.2 (0.86)
8/21/01	5	1.52 (0.13)	9.40 (1.29)	5.04 (0.17)	0.49 (0.08)	5.2 (0.37)	19.8 (2.06)

